CASK – Open Source Custom Architectures for Sparse Kernels

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What is Sparse Algebra?

- **Sparse Algebra** = Solving Sparse Linear & Nonlinear Systems of Equations
- Physical systems are often modelled as large, sparse sets of nonlinear equations
- **Sparsity** can be exploited to improve performance & reduce storage size
Need for Customisation in Sparse Algebra

For any sparse system – sparsity pattern, value range, order and nature of the algorithm may be used to improve performance

➡️ Custom Computing for Sparse Algebra
CASK – Custom Architectures for Sparse Kernels

Sparse Matrix Benchmark

Open Source Tool
http://caskorg.github.io/cask/
FPL14, FCCM15, FPGA16

Generic Architecture

FPGA Implementation

Source: University of Florida Sparse Matrix Collection

Source: www.nallatech.com
Custom Architectures for Sparse Kernels

From FPGA Accelerator DRAM:

- col ptr, values, col idx
- k inputs
- Cache C
- k inputs

Control Unit → Vector Unit

Parallel Reduction (in row)

Serial Reduction (in row)

Serial Reduction (in partition) $C_b$

Cache Structure (Replicated vs Dynamic) - trade-off storage size/maximum order vs retrieval rate

- k-way replication
  + $k$ reads / cycle
  - $k \times V_c$ storage
  - increases traffic
  - increases resource usage

Dynamic Routing

Result Cache (On-Chip vs Off-Chip) - trade-off latency/performance vs problem size/resource usage

- $+ \sim 13$ cycles latency
- $+ \text{support sparse vector}$
- $n < 100K$
- $\text{more BRAMs}$

- DRAM

- $- \sim 30K$ cycles latency
- $n > 100K$
- $\text{fewer BRAMs}$
Table 1: Required architectures for each matrix, produced in our approach (for Maxeler Vectis)

<table>
<thead>
<tr>
<th>Name</th>
<th>Order</th>
<th>Nonzeros</th>
<th>Nnz/row</th>
<th>Cx</th>
<th>k</th>
<th>Np</th>
<th>Cb</th>
<th>Logic/DSP/BRAM %</th>
<th>Peak Performance</th>
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</table>

**Fully Support Wide Range Of Problems**  
**Generate Optimised Architectures**  
**Improve Performance and Resource Utilisation**  

Future: application- and system-specific optimisations; run-time reconfiguration; energy reduction
Consider Instance Specific Custom Computing for Sparse Matrix Problems!

http://caskorg.github.io/cask